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Experimental Evaluation on the Performance of Zigbee Protocol

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Abstract: ZigBee protocol is one of the most common protocols in wireless sensor networks (WSNs) of low bandwidth, low cost, high level of security, and low power consumption. This protocol supports mesh, tree, cluster tree and peer-to-peer topologies. In multi-hop mesh topology, ZigBee defines three types of devices which are coordinator, router and end devices. Routers consume much more power than end device nodes. This research will conduct Received Signal Strength Indicator and throughput measurements to measure the performance of the XBee-Pro S2B module which supports ZigBee protocol. Additionally, the coverage range of XBee-Pro S2B in indoor and outdoor scenarios in real world conditions plays an important role in this project. Therefore, measurements will be conducted to investigate the coverage of the XBee-Pro S2B at different scenarios. Besides that, it uses development kits such as XBee Explorer USB and Arduino XBee Shield for range test and some supported tools for XBee modules such as X-CTU to design the wireless sensor network and carry out the measurements. Arduino Uno will be implemented in this project to utilize with XBee-Pro S2B module. This research involves the study of architecture of WSN and device types with signal outage in real life conditions. Based on the results obtained for RSSI, the indoor environment limits the coverage of the network compared to outdoor (line of sight). Although multi-hop can significantly extend the coverage the throughput of network degrade significantly as function of packet length.

Keywords: Wireless Sensor Network, ZigBee, RSSI, Multi-hop

1.0 INTRODUCTION

A wireless sensor network (WSN) is a special ad-hoc, multi-hop and self-organizing network that consists of a huge number of nodes deployed in a wide area in order to monitor the phenomena of interest. They can be useful for medical, environmental, scientific and military applications [1,2]. WSN mainly consist of sensor nodes or motes responsible for sensing a phenomenon and base nodes which are responsible for managing the network and collecting data from remote nodes. However, the design of the sensor network is influenced by many factors including scalability, operation system, fault tolerance, sensor network topology, hardware constraints, transmission media and power consumption.

ZigBee protocol is a communication technology which represents a key feature of designing low-rate, low power consumption, self-organizing and self-healing large-scale networks. ZigBee supports a variety of network topologies, such as peer-to-peer, star, cluster tree and mesh topology [2,3]. A challenging part in designing WSNs is that the nodes have limited power supply and in some applications it is not possible to change the battery or recharge it. A failure of a node may cause the failure of the whole network. In WSN design, choosing a topology such as a minimum number of routers is used with a large number of end devices can play a significant role in reducing the power consumption [3].

Therefore this paper investigates the 'real world' performance of a ZigBee compatible device for indoor and outdoor environment under direct and multi-hop transmission. The data presented in this paper will enable wireless network engineer to gauge the expected 'real world' performance of a wireless sensor network.

The paper is organized as follows. Section 2 outlines the performance metrics used to analysed the performance of ZigBee. The experimental setup as well as the types of wireless sensor nodes used is described in Section 3. Section 4 explains the scenario in which the experiment was conducted. The experimental results are presented and discussed in Section 5. Conclusion is drawn in Section 6.

2.0 PERFORMANCE METRICS

According to [4,5], there are a few factors that need to be considered in order to analyse the performance of the wireless sensor network. The factors that need to be considered are energy consumption, required coverage or the type of the information required. Besides that, received signal strength indicator (RSSI) will be focus in order to see the performance of real time XBee. Similarly, common performance indicator such as network throughout and packet delay also important in designing a wireless sensor network.

Received signal strength indicator (RSSI)

Received signal strength indicator (RSSI) is the signal strength received by a particular wireless sensor node given off by other nodes on a particular channel [4,5,6]. Signal strength is based on several factors, including the output power of the transmitter which means the original strength of the signal, the sensitivity of the receiver on how well the receiving device can hear weak signals, the gain of the antennae at both ends of the path, and the path loss, or attenuation of the signal as it travels through the air from the transmitter to the receiver.

Throughput

Throughput is the amount of data received per unit time [4,5] and can be calculated according to equation (1):

$$Throughput = \frac{Total\ Data\ Received}{total\ transmission\ time\ (\text{sec})} \quad (1)$$

Different values of packet length and baud rate give different value of throughput measurement. Theoretically, the network throughput increases as the baud rate increases. According to ZigBee standard, it guarantees a transmission date rate of 250kpbs. The throughput decreases as the number of hope increases.

$$Throughput\ decrease = \frac{1}{\eta hops} \quad (2)$$

Baud Rate

Baud Rate can be configured as bits per second. The transferred bits include the start bit, the data bits, the parity bit and the stop bits. However, only the data bits are stored. The baud rate is the rate at which information is transferred in a communication channel.

3.0 EXPERIMENTAL SETUP

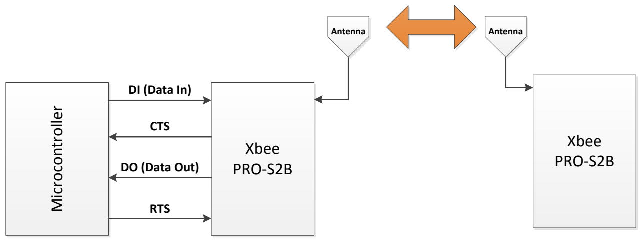

Fig 1. Block Diagram for transmit and receive nodes

Fig. 1 shows the block diagram for transmit and receive nodes that will be designed through the experiment. XBee Pro-S2b will be attached with Arduino Uno and act as a coordinator. The coordinator will transmit data to the router which is the receiver node. The RTS represent as a Request-to-Send Flow Control and if enabled it is an input. The CTS represent as a Clear-to-Send Flow Control and if enabled it is an output. Another node is router where XBee Pro-S2b will be attached to XBee Explorer USB. In this experiment, there will be two types of transmission that will be conducted which are Direct Transmission and Transmission through One Router.

Direct transmission

Direct transmission or also known as a single hop as depicted in Fig. 2, is a communication link whereby data from coordinator is transmitted directly to router or end device. In wireless sensor network, the XBee nodes which are collecting data can send information directly to the access point using a one direct path rather than following a path in which data has to be routed through different nodes. This kind of communication is good in short distances as the nodes have limited power and can transmit to limited distances.

Fig 2. Block Diagram for direct transmission

In order to develop a WSN, XBee Pro-S2B modules are used in this with Arduino Uno R3 as shown in Fig.2. Therefore, all the results obtained through this project will referred with real implementations of ZigBee network. This will contribute to a better understanding about the capabilities and performance of ZigBee technology for real life wireless sensor deployments.

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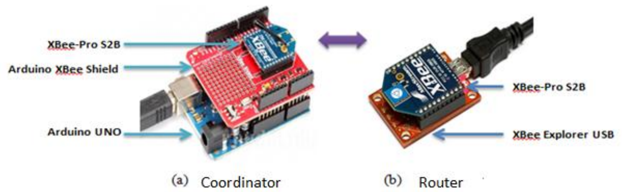

Fig 2. Testbed setup

Multi-hop transmission

Multi-hop transmission as shown in Fig. 4 requires router to relay the communication between the coordinator and the end device[4,7]. A router will received data from the coordinator and send to end device. In the multi-hop communication, the energy will be conserved as considering the large distances where the single hop communication may not work efficiently. Multi-hop would be better to be used for the long distances. However, multi-hop can cause some delay because of data aggregation with the intermediate nodes. This latency may be decreased by reducing the distance between the nodes, but still there might be some delay as the intermediate nodes may wait for the data to be arrived. The multi-hop performance of the XBee Pro-S2B network as shown in Fig.5 is measured to compare with the point-to-point network results. The same technique with the previous experiment is applied.

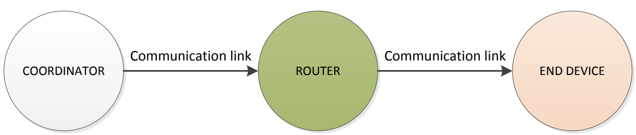

Fig. 4 Block Diagram for multihop transmission

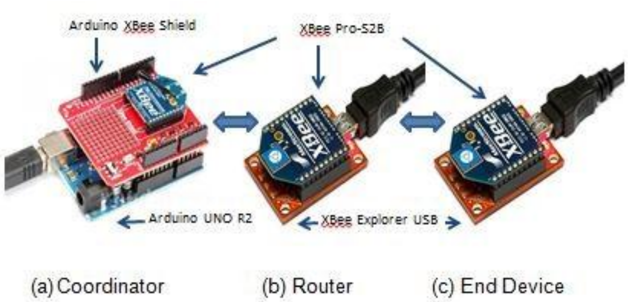

Fig.5 Testbed setup for multi-hop network

4.0 METHODOLOGY

The experiment was conducted in in two different environment in order to obtain the RSSI and throughput measurements.

Indoor

The indoor experiment was conducted in the hallway of Universiti Kuala Lumpur British Malaysian Institute as shown in Fig.6.

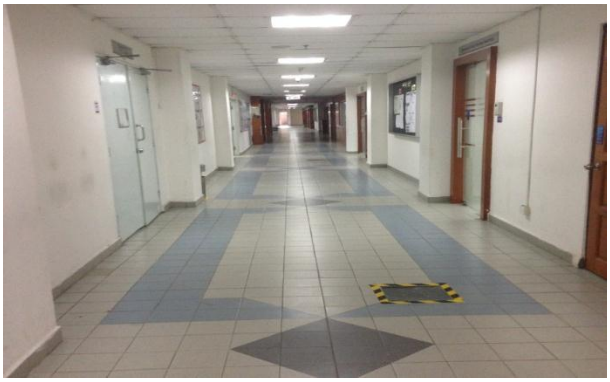

Fig 6. Indoor test range

The RSSI value for is measured after sending 50 packets of 32 bytes each. The transmission range were varied up to 40 meters. The distance between the Coordinator and the End Device is varied to measure the relationship between RSSI values and distances.

To measure the throughput of the XBee Pro-S2B module, the baud rate and the packet length were initialized. Afterwards, the time taken for data to be transmitted from coordinator to the router was measured to analyze how does the baud rate affects the latency for communication over ZigBee protocol. The transmitted packet length packet were limited to 80 bytes only in order to avoid reception overcharge [4]. Measurement in comparison to different values of packet length and baud rate were carried out.

Outdoor (line of sight)

For the RSSI and throughput measurements in outdoor, the same technique of the previous experiment was applied. The experiment is conducted at the field of Universiti Kuala Lumpur British Malaysian Institute as shown in Fig.7. There are no trees and obstacles with the transmission range up to 40 meters.

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Fig 7. Outdoor test range

5.0 RESULTS AND DISCUSSION

The analysis of the collected data is discussed according to its scenarios. To reduce measurement errors, for each scenario the experiment was repeated 5 times.

Received signal strength indicator (RSSI) measurements

The RSSI value is measured after sending 50 packets of 32 bytes each. The distance between the Coordinator and the End Device was varied to measure the relationship between RSSI values and the distance. Power Transmit, P_t that being used was 2dBm.

Fig. 8 shows that the RSSI level decreases with distance. At a distance of 50m in indoor the RSSI becomes -86dBm which is the last recorded RSSI where the percentage of received good packet is 100%. In indoor scenario, the signal strength is not linear as the distance linearly increased because of multi-path fading and indoor shadowing effects. From the graph, it shows that non-linear path loss becomes more as the distance increase, leading to difficult accuracy achievement. However, indoor area is always smaller as compared to outdoor. Thus, the node location becomes obvious as the accuracy is worst. . The way to tackle this problem for better estimation accuracy needs to be studied.

For outdoor, nodes are randomly put on the ground with the same level. The signal strength decreases as the distance increase.

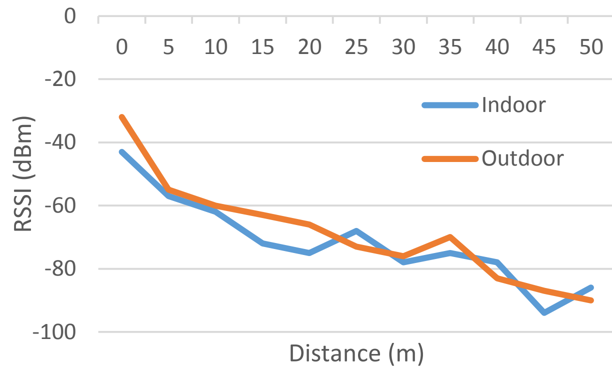

Fig 8. RSSI measurements

Throughput measurements

The throughput measurement for direct transmission, XBee Pro-S2B module configured as an End Device sends packets to Coordinator. Several measurements are carried out, in comparison to different values of packet length and baud rates.

The results for the direct transmission measurement is shown in Fig 9. The x-axis represents the size of packet sent and the y-axis represents the throughput value in kbps.

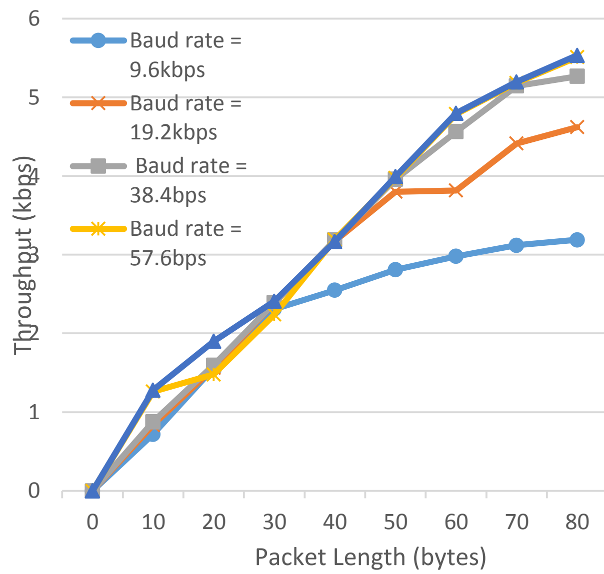

Fig 9. Direct transmission throughput measurements

The multi-hop performance of the XBee Pro-S2B were measured and compared to the results with point-to-point measurements. The previous experiment is repeated but with an addition of a Router to relay the transmission. The baud rate is set to 115200bps. The result of the multi-hop throughput measurement is shown in Fig. 10.

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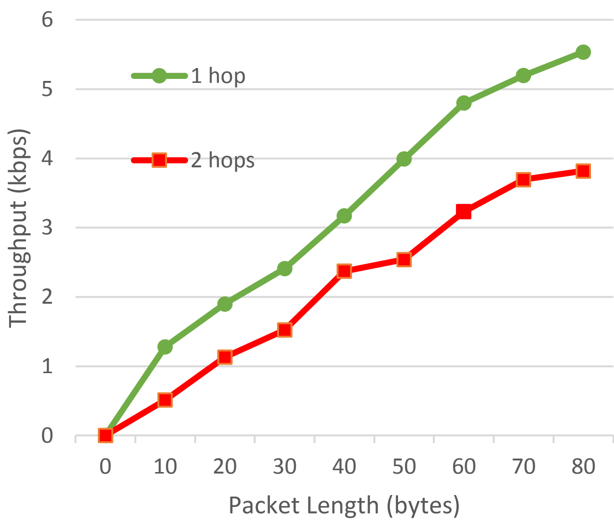

Fig 10. Throughput measurements for mulihop networks

The results in Fig.10 shows that the presence of the Router has a significant effect on the data rate and throughput of the entire network. The throughput decreases as the number of hop increases. In case of direct transmission, the End Device sends data packet directly to the Coordinator, therefore the transmission channel is always free. For multi-hop network, when the Router retransmits its packets to Coordinator, the medium is occupied. Therefore, the End Device must wait before transmitting the new data packet.

6.0 CONCLUSION

In this paper, the performance of the Zigbee based WSN has been tested in various environments. Typical performance indicators including RSSI and rate of successful received packet have been analysed throughout the tests. Apart from that, distance between two communicating nodes is also proved to have impacts on the performance of the network with direct transmission from the End Device to the Coordinator and with the presence of Router for relaying packet transferred.

It is observed that, the maximum achievable throughput for ZigBee is less than 6kbps. This findings is supported by the experiment conducted by [4]. Overall, the performance analysis shows that the XBee Pro-S2B module is more suitable for low data rate applications.

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